WORKSHOP ON MESOSCOPIC AND NANOSCOPIC SCIENCE USING X-RAY TECHNIQUES

Introduction to Workshop

Eric Isaacs (ANL)

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Workshop Chairs

August 29 – September 1, 2004, The Abbey, Fontana, Lake Geneva Area, WI

Scientific Program Advisory Committee

- ***Pierre Petroff (UCSB)***
- ***Ian Robinson (UIUC)***
- ***Woowon Kang (U.of C.)***
- ***Alan Hurd (LANL)***
- ***Ivan Schuller (UCSD)***
- ***Heinrich Jaeger (U. of C.)***
- ***Sunil Sinha (UCSD)***
- ***Eric Isaacs (ANL)***

Workshop Scope

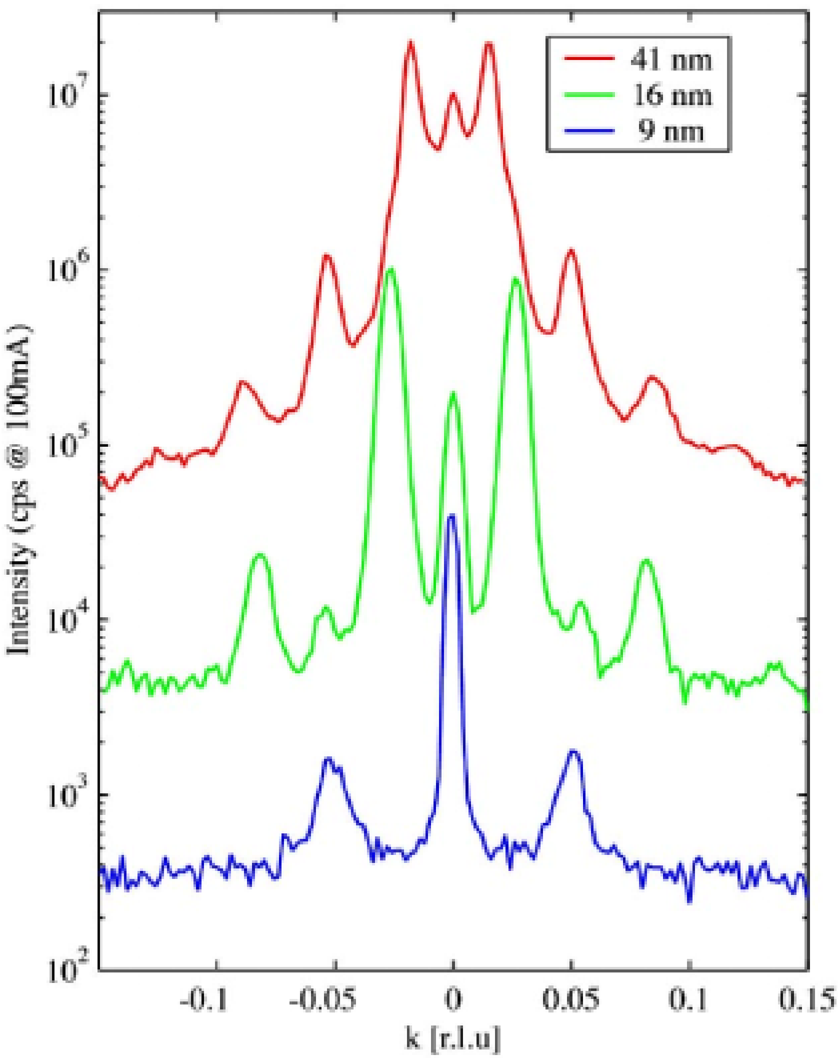
- **To understand the fundamental behavior of individual building blocks of mesoscopic and nanoscopic systems, which are combined into more complex structures leading to systems with new functionalities.**

- **Evaluate the advances in mesoscopic and nanoscopic science that are exciting and significan. (What are the key issues/questions?)**

Workshop Scope (contd.)

- **Areas of mesoscopic and nanoscopic materials where x-ray characterization techniques will advance the synthesis**
- **Discuss potential new x-ray methods which will provide insight into mesoscopic and nanoscopic properties and behavior. (How can we use SR to address some of these key issues/questions?)**

Grand Challenges In Understanding Mesoscopic and Nanoscopic Materials Properties and Opportunities for X-ray Techniques to Address them



Stripe formation in $PbTiO_3$ thin films of 9 nm, 16 nm, and 41 nm thicknesses. This figure shows synchrotron x-ray scattering patterns acquired at the APS, along an in-plane (010) lattice vector, revealing modulation peaks around the $PbTiO_3$ Bragg peak located at k=0. These modulation peaks are thought to arise from a periodic stripe structure developed in the plane of these films, due to a polarization density wave arising from 180° domain formation.

Some scientific issues

- **Atomic, Electronic and Magnetic Structure of Nanoparticles and assemblies of nanoparticles.**
- **Dynamics of these systems.**

Some scientific issues

- **Effects of Confinement or Finite Size**
- **Proximity Effects**
- **Organization Effects (e.g. patterning; self-organization; cooperative phenomena)**

Interesting Basic Science Questions

Phase Transitions when the Correlation Length exceeds the System Size

- **New Spin and Charge Ground States and Excitation Spectra**
- **New Dynamics for Polarization and Charge Transport**

Confinement and Finite Size

- **3D**

  Nanocrystalline Materials; (single-grain, sintered, lower dislocation density)

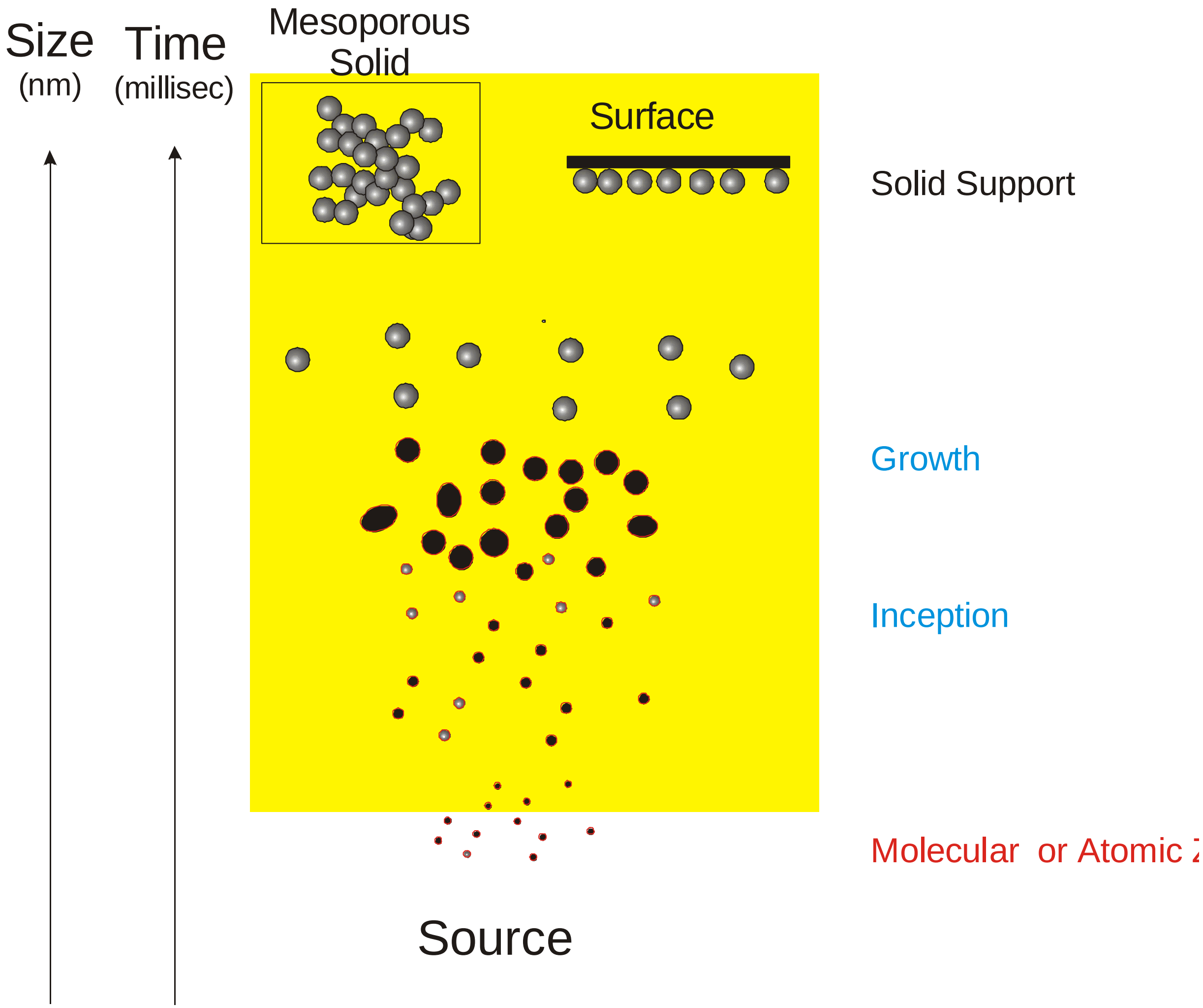
  Cluster Compounds, Bucky Balls, etc.

  Fluids in Nanoporous Media

  Quantum Dots; Droplets; Deposited Clusters

  Single Macromolecules

AFM image of self-assembled nanoscale islands of $La_{0.66}Sr_{0.33}MnO_3$ (15 - 60 nm diameter) on (a) $LaAlO_3$ and (b) $SrTiO_3$.



SAXS can probe these structures in real time.

Confinement and Finite Size

- **2D**

  Thin Films; Fluids confined in Channels; Layered Compounds; Multilayers

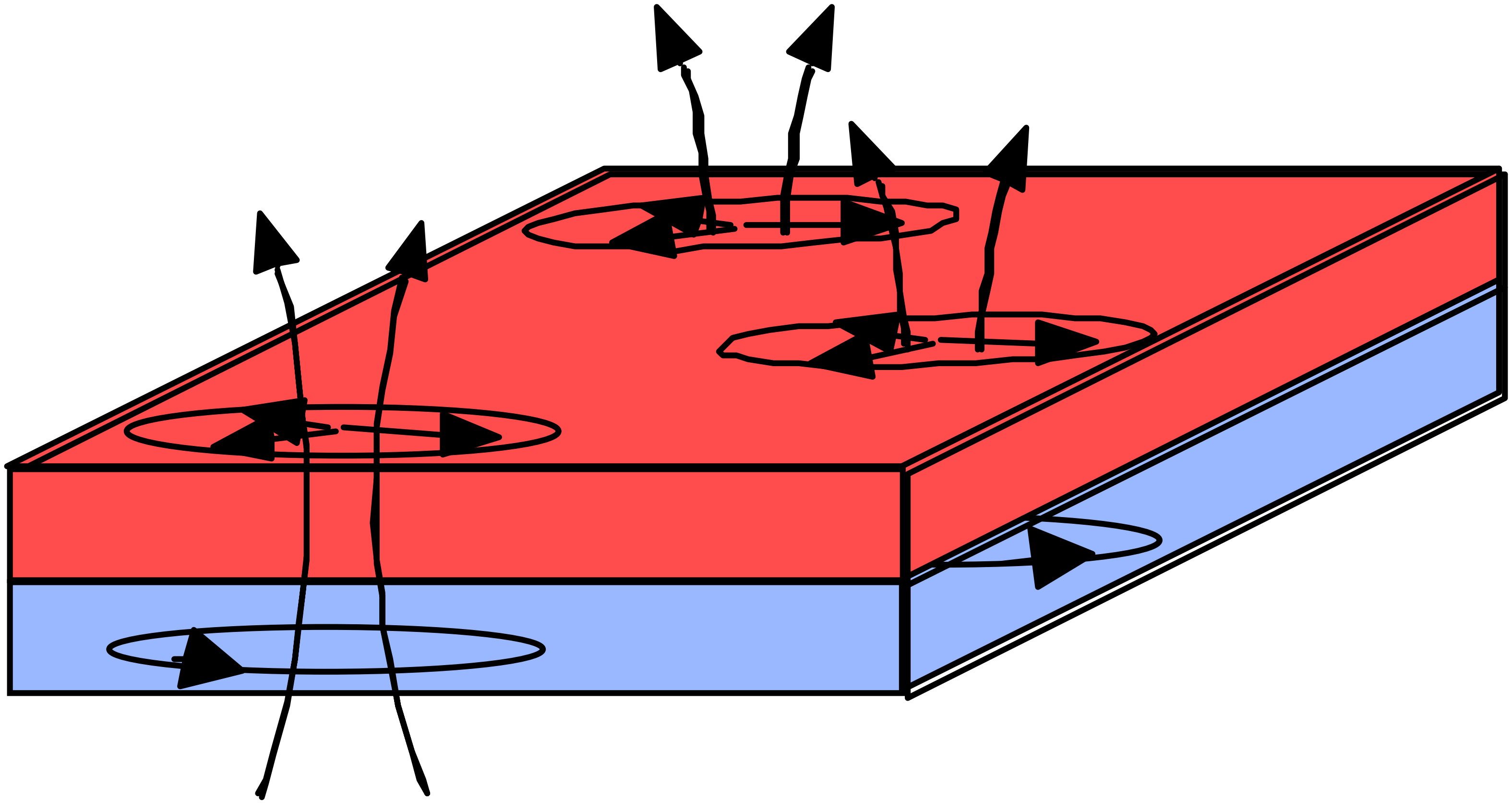
  Quantum or Magnetic Dot Arrays

  Carbon nanotubes

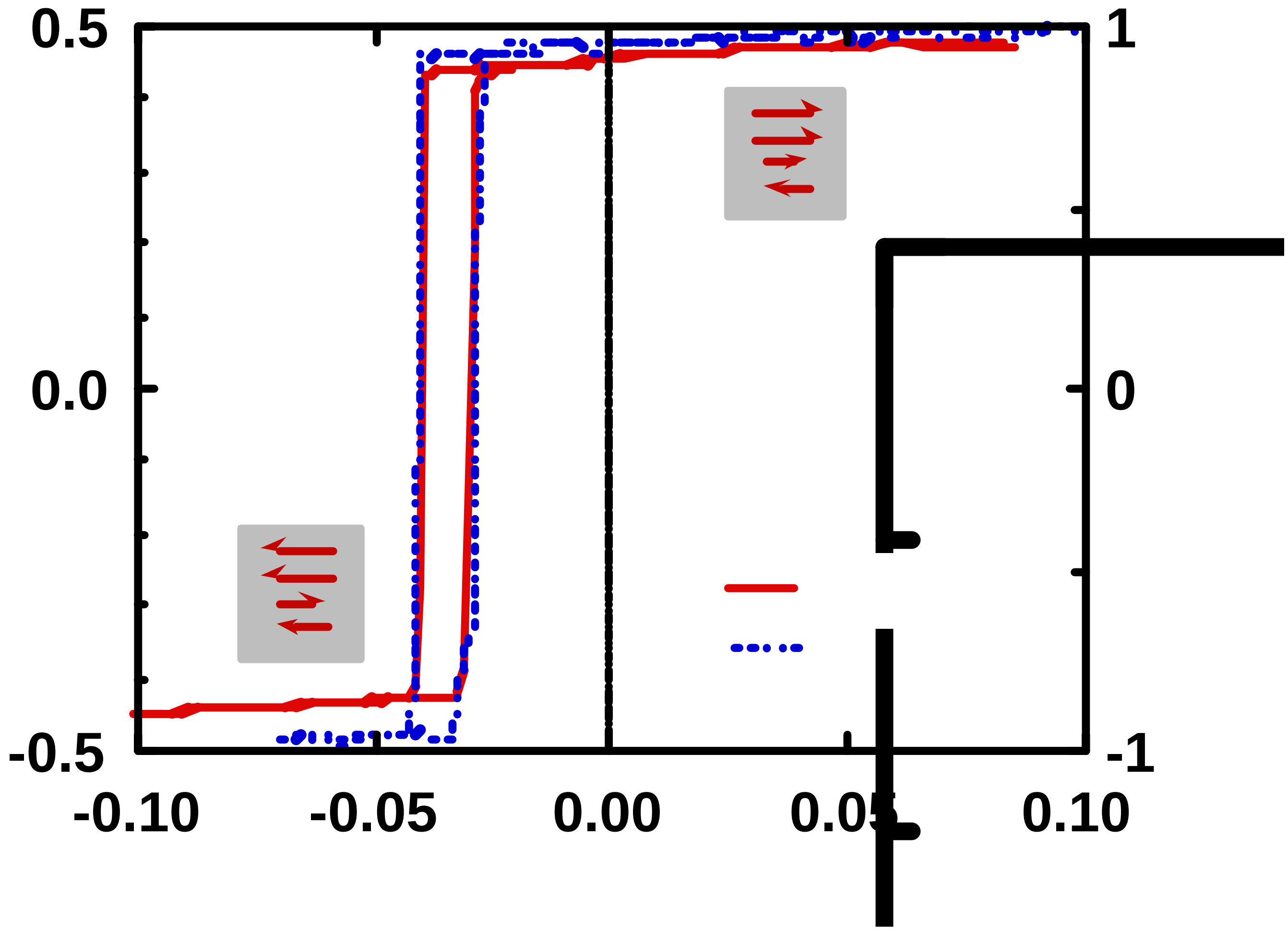
- **1D**

  Quantum Nanowires

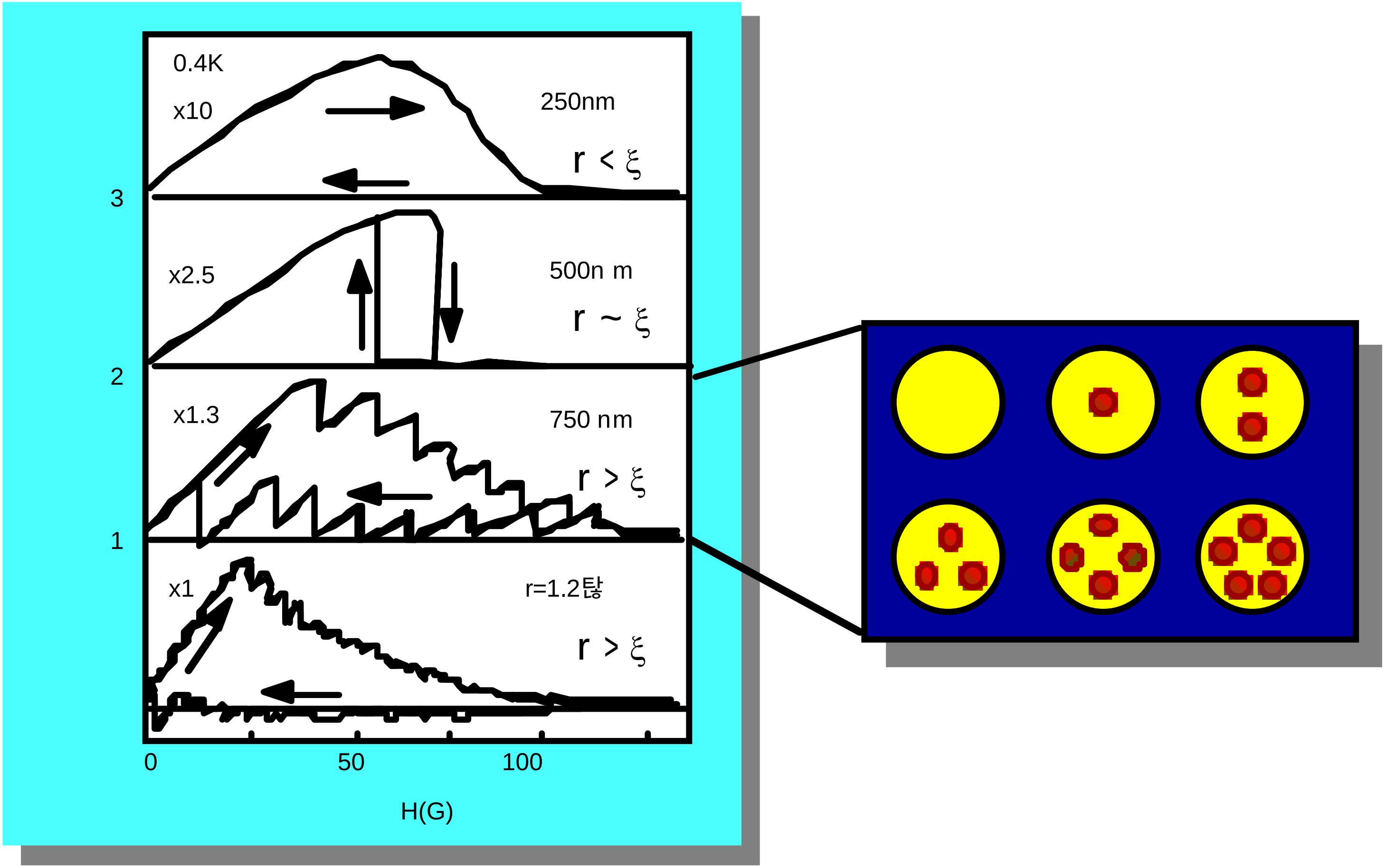
  Fluids, Molecules in Carbon Nanotubes



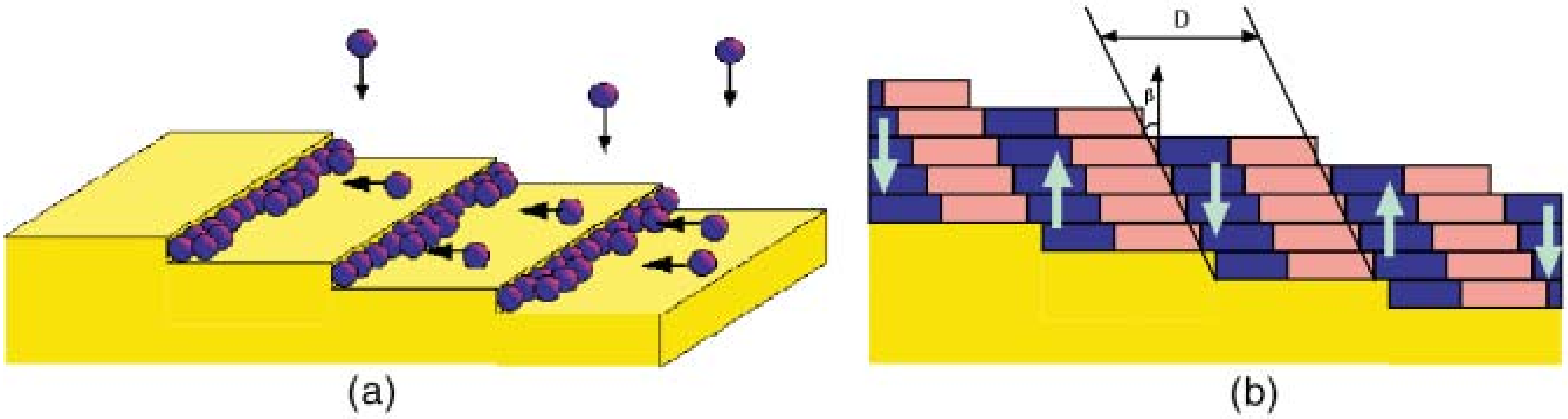
Hybrid structures formed by the magnetic field of vortices in the superconducting layer (blue) inducing magnetic textures in the magnetic layer (red).



Offset hysteresis loop arising from exchange bias.



Magnetization of vortices confined to an Al disk of 130 nm thickness and various radii (from Geim et al.). Inset shows vortex configurations predicted by Ginzburg-Landau theory.



(a) Adatoms diffuse along terraces of a vicinal surface and form stripes or nanowires along the step edges. (b) Tilted superlattice by sequential step decoration.

Potential Applications

- **Novel Electronics**

  "Spintronics"

  High and Low Dielectric Constant Materials

  Molecular Level “Chips” and Quantum Computing

Potential Applications

- **Information Storage and Retrieval**

  Giant Magnetoresistance, Spin Valves

  High Density Magnetic Storage with Long-Term Stability

- **New, High Strength Materials**

Characterization Tools for Nanoscale Materials

- X-ray and Neutron Scattering
- Electron Microscopy
- AFM, STM, MFM, NSOM
- Scanning X-ray Nanoprobe

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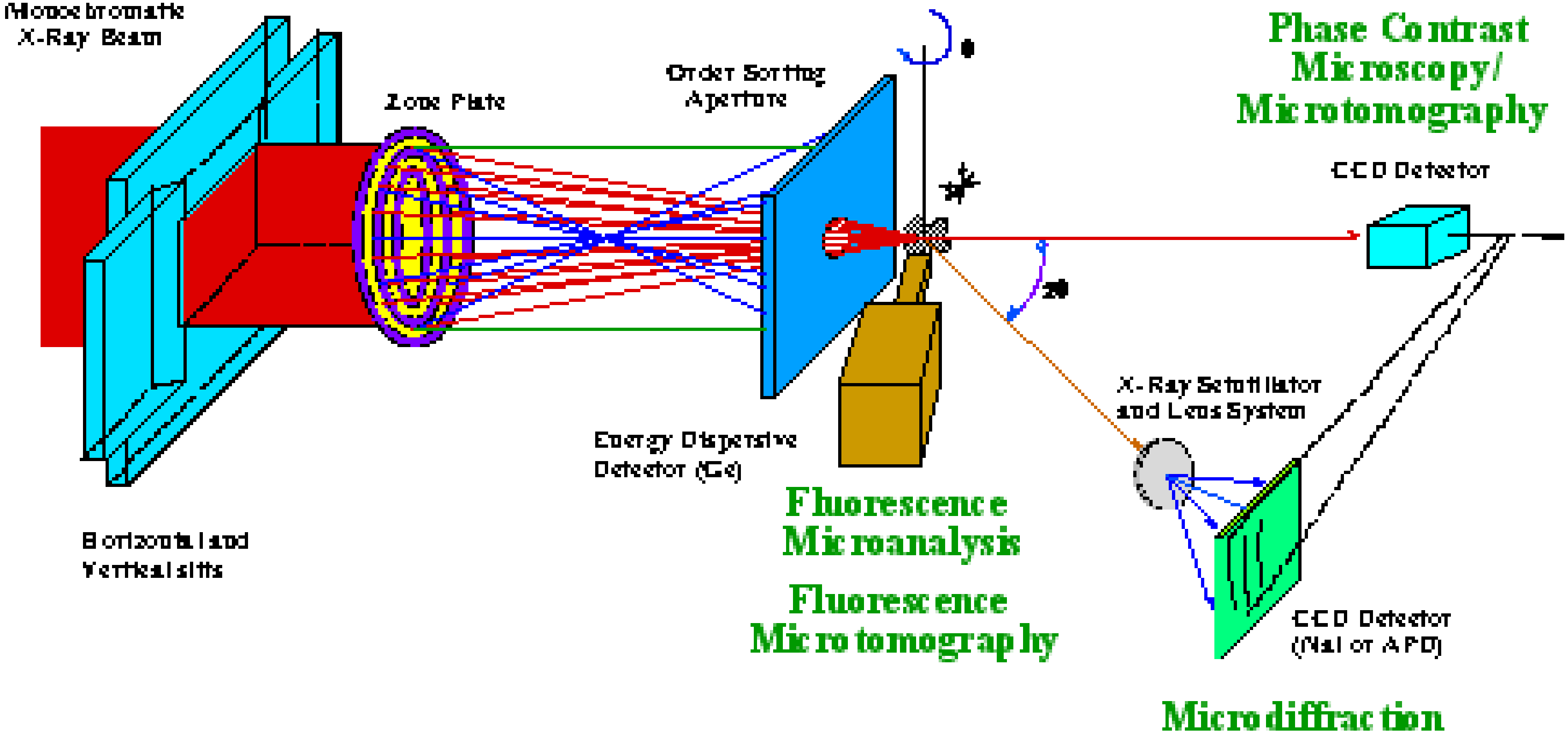
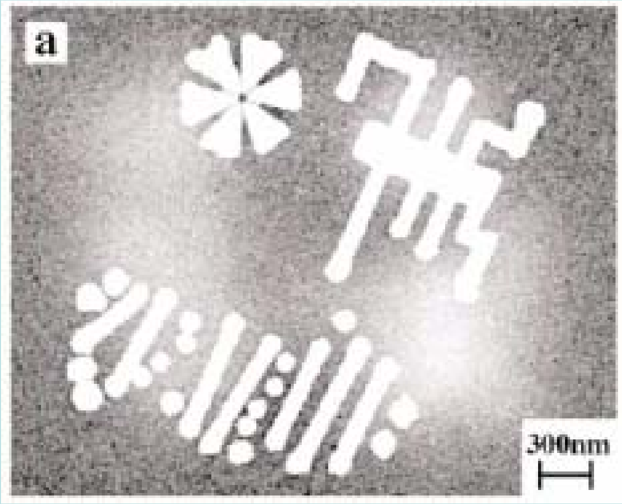
Characterization Tools for Nanoscale Materials

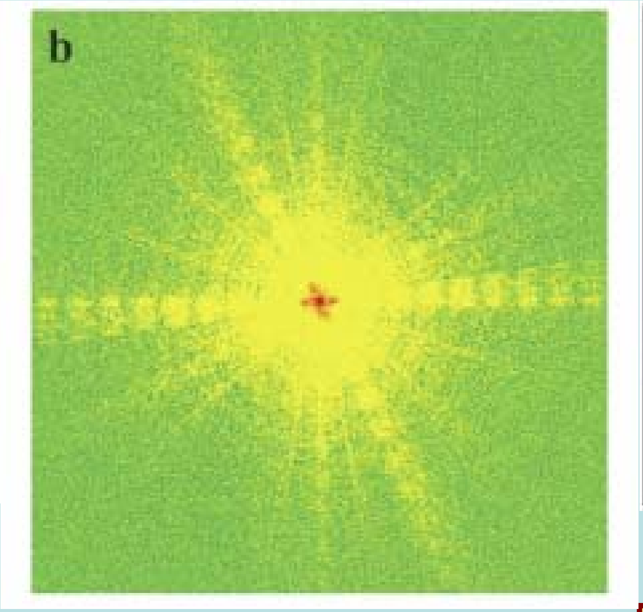
- X-ray Imaging Techniques
- PEEM and Photoemission Spectroscopy
- Computer Simulations and Theory

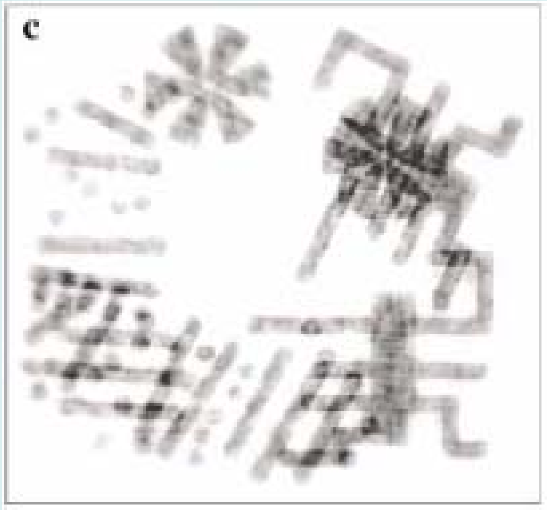


Schematic of a scanning x-ray nanoprobe using zone plate focusing.

DIFFRACTION IMAGING BY J. MIAO ET AL





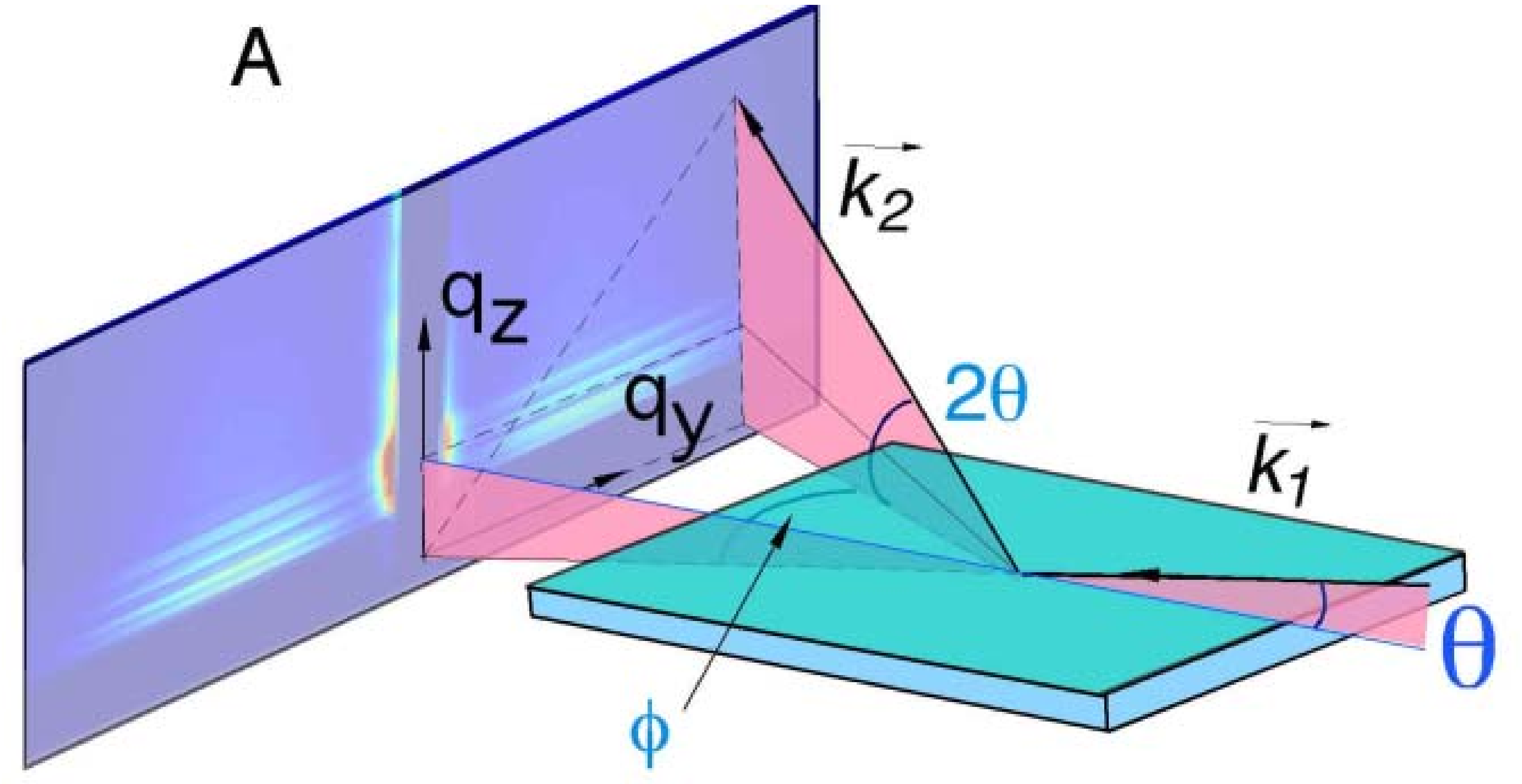


- From Miao, Ishikawa, Johnson, Anderson, Lai, Hodgson PRL Aug 2002
- SEM image of a 3-D Ni microfabricated object with two levels 1 μm apart
- Only top level shows to useful extent

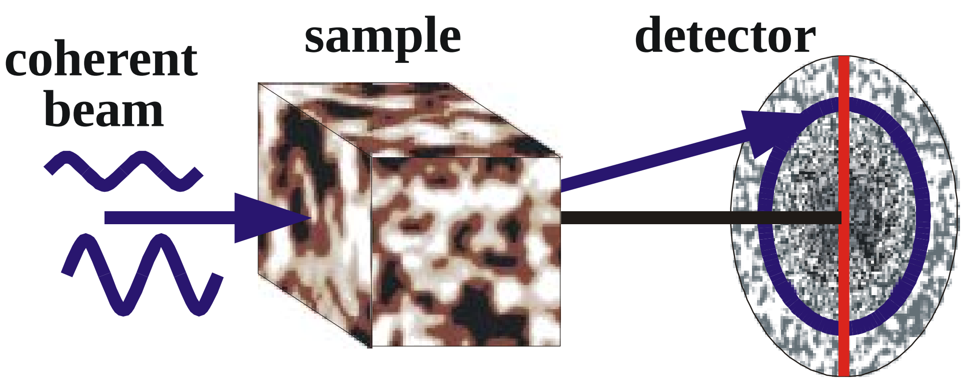
- Diffraction pattern taken at 2 Å wavelength at SPring 8

- 2-D reconstruction with Fienup-type algorithm
- Both levels show because the depth of focus is sufficient
- Resolution = 8 nm (new record)

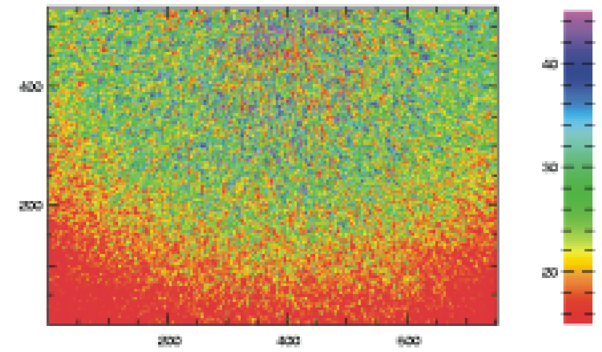
GISAXS

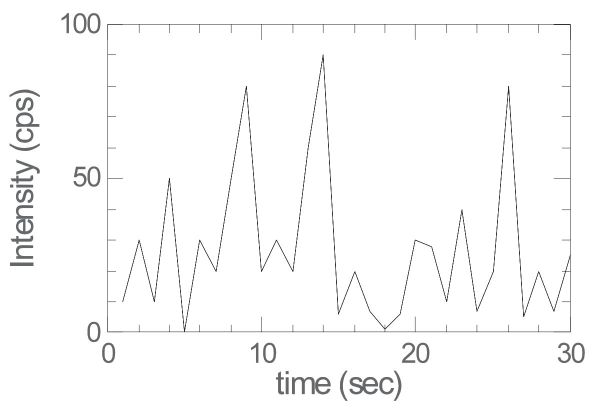


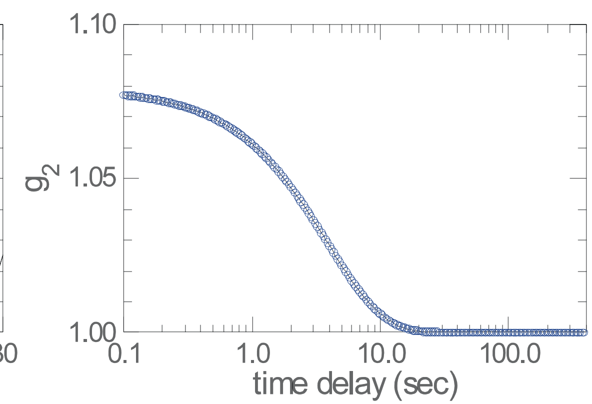
Photon Correlation Spectroscopy



X-ray speckle pattern from a static silica aerogel







$$g_2(\boldsymbol{q},t) = \frac{\langle I(\boldsymbol{q},t')I(\boldsymbol{q},t'+t)\rangle}{\langle I(\boldsymbol{q},t')\rangle^2}$$

$$\begin{aligned} g_2(t) &= 1 + \beta\, \exp(-2\Gamma t) \\ &= 1 + \beta\, \exp(-2t/\tau) \end{aligned}$$

β:speckle contrast

SR can play several kinds of roles

- Characterizing ,via imaging, details of defects in nano-objects assumed to be ideal
- Providing, via scattering techniques, global averages of same.
- Investigating basic physics of these objects, e.g. phase transitions, excitation spectra, aggregation, etc.

Practical Challenges

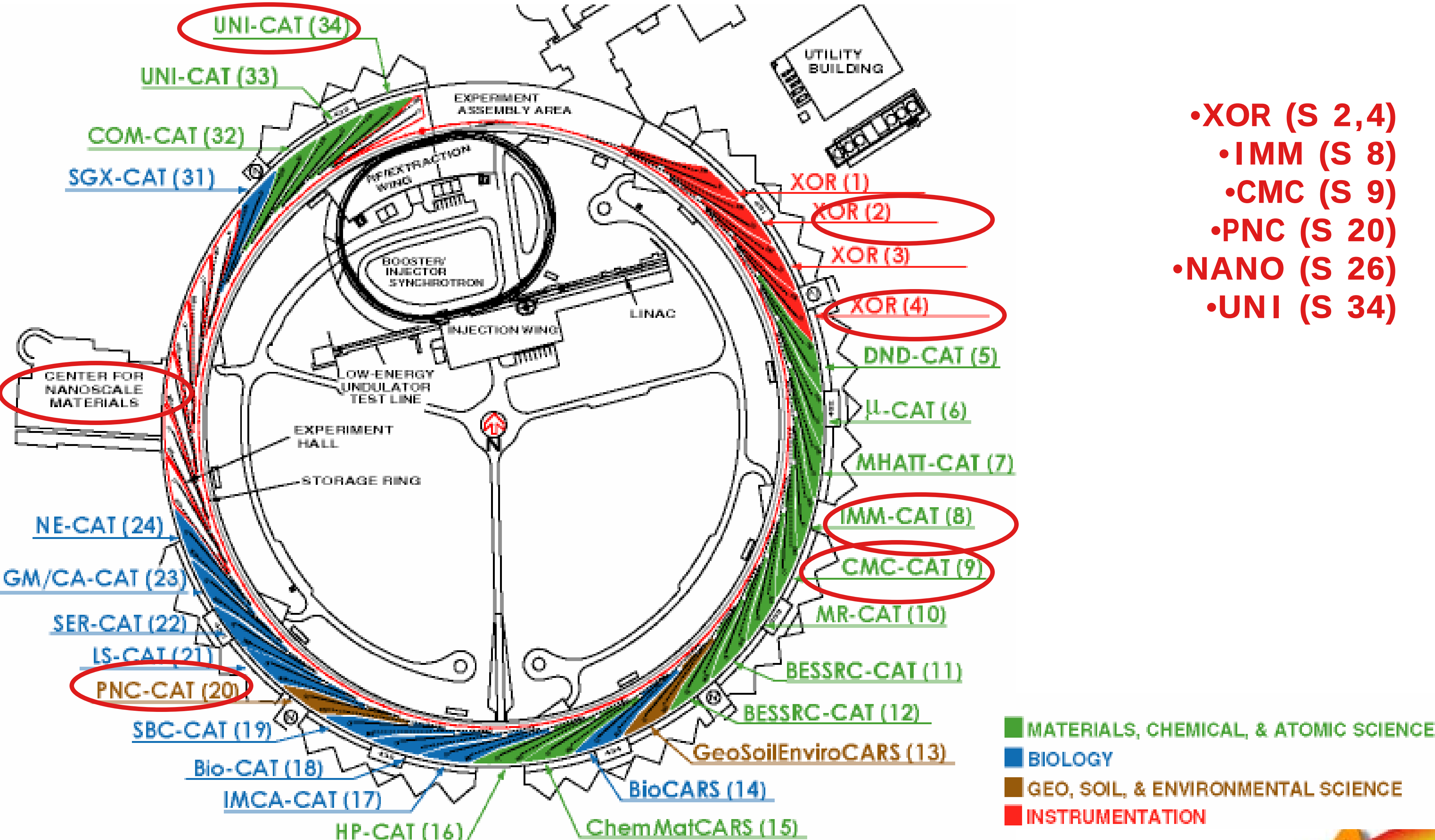
- *Higher beam brilliance with preserved coherence*
    - *Enhancing coherence*
    - *Photon energy ranges of interest*
    - *Nanofocus capabilities*

- *Techniques required to address scientific challenges -?*

- *Unique experimental environments*
    - *In situ measurements during synthesis*
    - *Controlled environments to produce membranes to nanojets*
    - *Integration of laboratory based techniques with x-ray tools (E.g. Optical measurements)*
    - *Need for large magnetic and electric fields*
    - *Angstrom accuracy and reproducibility scanning stages*

- *R&D new x-ray techniques, Etc., Etc……………….*

APS Nanomagnetism Study Capabilities



- XOR (S 2,4)
- IMM (S 8)
- CMC (S 9)
- PNC (S 20)
- NANO (S 26)
- UNI (S 34)

Draft Workshop Objectives

1. **Explore the breadth of mesoscopic and nanoscopic science covered by the workshop topics, *not* limiting to synchrotron techniques alone. What are the key questions/issues?**

2. **Identify opportunities for continued scientific and technology discoveries using the APS and Center for Nanoscale Materials (CNM) during the next 5-10 years and their potential impact.**

3. **Identify new scientific proposals/programs specific to the emerging areas of meso- and nano-materials that the participants will bring to the APS during next 5 to 10 years. Also evaluate the capital and operational requirements for these proposals /programs.**

Draft Workshop Objectives

4. **In addition to available beamline capabilities at the APS, identify future needs to support research in this area of science and technology.**

5. **Address R&D in enhancing the capabilities of the APS to support the area of meso- and nanoscopic science.**

6. **Address the need and support for theoretical work to strengthen the experimental research.**

7. **Prepare a summary document for the archival literature to serve as a roadmap for the meoscopic and nanoscopic research using x-rays at the APS Source and suggest the role of the Advanced Photon Source towards this objective.**

Charge to the Participants

1. Identify grand challenge mesoscopic and nanoscopic science that should be addressed during next 5-10 years using x-ray techniques at a third generation synchrotron radiation source.
2. Identify and justify the technical requirements to meet the grand challenge problems:
   - New instrumentation and techniques that need be developed on existing beamlines to perform new kind of science.
   - Need for new dedicated beamlines and instrumentations for this community
3. Identify both short- and long-term R&D needs in areas such as x-ray techniques, sample environment, optics, and data anlysis that will prepare the community to address grand challenge problems

- The summaries and slides provided by the speakers of the talks can be accessed directly by clicking the ‘summary’ or ‘slides’ in the ‘program’ on the workshop website.

http://www.future.aps.anl.gov/Future/Workshops/Mesoscopic_and_Nanoscopic_Science/Program.htm

- You can continually input your thoughts using the ‘Swiki’ software linked to the lap-top using Wi-Fi Input can be made even after the workshop.

http://swiki.anlgh.org/Mesonano
Login Name: meso
Password: nano

- Address the applicable objectives in each of the topics in the scope of the workshop after each talk and make recommendations to the APS

APS Strategic Planning Meeting

"Future Scientific Directions" September 2 & 3, Fontana, Wisconsin

www.future.aps.anl.gov/Future/Strategic_Planning_Meeting/home.htm

	Thursday Sept. 2, 2004	Friday Sept. 3, 2004
8:00 am	Introduction & Charge	
8:30 am	Report on Time Domain Workshop	Report on Nanomagnetism Workshop
9:30 am	Report on Inelastic Scattering Workshop	Report on Big Magnet
10:00 am	Break	Break
10:30 am	Report on Imaging Techniques Workshop	Report on High-Energy X-rays Workshop
11:30 am	Report on Meso/Nanoscopic Workshop	Report on Biological Crystallography Workshop
12:30 pm	Lunch Break	Lunch Break
2:00 pm	Report on Membrane Science Workshop	Discussion and Wrap-Up
3:00 pm	Report on BES-Funded Sectors Science	
3:30 pm	Break	
4:00 pm	Report on Environmental Workshop	Adjourn
5:00 pm	Report on Soft X-rays Workshop	
6:30 pm	Dinner	